examination of the spectra from this point of view is most suggestive. In some of these stars the hydrogen lines are bright and double on a broad dark band, and it has been supposed that they are "double reversals," similar to those of calcium lines in the Sun. Pickering has found that in all cases where the hydrogen lines present this appearance the accompanying dark lines of the spectrum are very wide and feeble. Rapid rotation is therefore suggested by the appearance of the dark lines, and the foregoing investigation suggests that under these circumstances the bright lines would appear double, as we actually see them. There is a possible test as to whether in such stars we really see the effects of rotation—namely, that in stars like δ and μ *Centauri*, which resemble γ *Cassiopeiæ*, except that the dark lines are much less diffuse, the bright lines should either be single or only very closely double, whereas if they are "double reversals" their appearance would seem to be independent of the character of the dark lines. Dr. McClean informs me that his photographs of these spectra do not furnish conclusive evidence on this point, since the dispersion employed was insufficient to exhibit the doubling of the lines in γ *Cassiopeiæ*. It may be added that in γ *Cassiopeiæ* the separation of the components of the double bright lines is five or six times as great as that in the case of the doubly reversed K line in the Sun.

It does not seem improbable, therefore, that some of the points to which attention has been drawn may be found to have a useful bearing on the interpretation of some of the peculiarities which are met with in a survey of stellar spectra.

Inquiry as to the Cause of the Shadow Bands upon the Earth which accompany Total Eclipses of the Sun. By G. Johnstone Stoney, M.A., D.Sc., F.R.S.

If, when the Sun is shining, we look at a shallow pool on the sand of the sea-shore, there is usually a sufficient ripple over the surface of the water to give rise to a very beautiful optical effect. The appearance consists of alternate bands of intense brightness and of shade which seem to travel over the sand at the bottom of the water in harmony with the motion of the waves at the top.

When we consider the cause of this phenomenon, we can see that if there were a second Sun in the heavens so situated that the bright and dark bands it would produce on the sand would coincide with the dark and bright bands of the first Sun, then the two Suns operating together would tend to produce a uniform illumination over the sand, and the appearance of bands would be lost. It is in this way that on a cloudy day, when light arrives from all directions, there is no trace of the banded

appearance. Thus we see that a sufficiently small size of the source of light is a necessary condition for the development of the phenomenon. And, in fact, when we trace the course of the rays refracted by the undulating surface of the water, we find that to produce the most vivid effect the angular size of the luminary must not exceed a certain maximum which depends on the refractive index of water, on the height of the waves, and on the ratio of the depth of the pool to the wave-length.

Now all this is closely analogous to what occurs during an eclipse, when shadow bands are seen swiftly to sweep over the landscape in the neighbourhood of that patch of the Earth upon which, for the time being, the eclipse is total. The umbra of the Moon as it passes down through the Earth's atmosphere is part of so acute a cone that the short portion which traverses the atmosphere is almost a cylinder. It may be likened, as regards the proportion of its length to its thickness, to an ordinary cedar pencil. The lower end of this cylinder reaches the surface of the Earth, and the whole cylinder is carried sideways through the atmosphere with a speed nearly twice the velocity of sound. Within the umbra the temperature of the air falls several degrees, and, as the umbra is hurried along, this low temperature affects different portions of air in succession. The umbra accordingly is, so far as the air is concerned, a cylinder of low temperature travelling sideways through the atmosphere, and surrounded by the penumbra, a larger cylinder, throughout which the reduction of temperature is less. As each situation is reached the low temperature causes condensation of the air and inrush.

The movement consequent upon this in so mobile and compressible a fluid as air will not be simple; especially where, as in most total eclipses, the section of the umbra is an area of very many square miles. Within the umbra it will consist of complicated alternations of density, but will give rise to more regular undulatory motion in the neighbourhood. The effects will be partly of the nature of forced vibrations owing to the advance of the umbra being swifter than sound, and partly determined by the rate at which waves in air, when once set up, will naturally advance. Under these circumstances we may expect that the air in the neighbourhood of the umbra will be differently affected in front of the advancing cylinder, at its sides, and behind it. In front of the umbra and behind it the effect seems likely to incline towards a state of turmoil, while as the sides are approached it may probably become a more regular undulation. It is here therefore that we should expect the most distinct shadow bands, while in front and in the rear of the umbra the phenomenon will probably assume the form of less regular patches.

Such bands occur because atmospheric waves travelling horizontally and of a length adapted to their elevation over the Earth, must produce alternations of light and shade upon the Earth, provided that the source of light has not too great an

angular size in the direction perpendicular to the bands. Hence it is that the bands are only seen when the arc of uneclipsed Sun has become thin. The intensified effect which can be obtained by reducing the size of the source of light is well seen in the neighbourhood of a naked arc light, which will be found to throw on the ground and surrounding walls a shadow of every considerable discontinuity in the density of the air, such as that over a lighted match.

It is easy to associate this phenomenon with the familiar twinkling of stars, which is due to more rapid and less intense alternations of air density, and therefore requires a still more minute angular size in the source of light. Thus it often happens that even the angular size of a planet has become too large for twinkling at times when fixed stars in the neighbourhood of the planet continue to twinkle perceptibly.

Addendum.

The waves dealt with in the above paper are likely to be of that more rugged type which involves a long series of strong harmonics; and it seems probable that some of these harmonics will be short enough to produce sound and may be sufficiently intense to be audible. The sound would probably be a rather confused hum like that heard in the neighbourhood of telegraph posts, but with a greater preponderance of the baser tones such as we hear in thunder. It would be interesting, therefore, to listen attentively for an effect of this kind, which if faint would perhaps be most easily heard as a somewhat musical note from stations at a moderate distance to the right and left of the track of totality.

Notes on the Total Eclipse of the Sun, 1900 *May* 28, *observed at Algiers.* By E. W. Maunder and A. C. D. Crommelin.

The watches used in the following time determinations were Usher & Cole 39936, and Isaac 10859, the latter having been kindly lent by the Hydrographer to the Admiralty, and the former by Messrs. Cole. The errors while at Algiers were obtained by comparison with the sidereal clock at the Algiers Observatory, whose errors were kindly communicated by M. Trépied. The longitude of the Observatory is assumed to be $12^{m}\ 8^{s}\cdot5$ E., the value given in the *Nautical Almanac.* (It may, however, be pointed out that the altitude of the Observatory, 65 feet, given in the *Nautical Almanac* is obviously in error: the correct altitude given by M. Trépied is 342·2 metres, or 1123 feet.) The following are the errors of the two watches on Greenwich Mean Time at the times when comparisons were made :—